CHAPTER 3

GEOTECHNICAL CONSIDERATIONS

3-1. Subsurface Investigations and Geology. The subsurface explorations are the first consideration from site selection through design. These investigations should be planned to gain full and accurate information beneath and immediately adjacent to the structure. The investigation program should cover the area of the foundation and, as a very minimum, extend 20 feet below the tip of the longest pile anticipated. The borings should be of sufficient depth below the pile tip to identify any soft, settlement-prone layers. The type of soil-boring will be determined by the type of soil profile that exists. In a clay layer or profile, sufficient undisturbed samples should be obtained to determine the shear strength and consolidation characteristics of the clay. The sensitivity of the clay soils will have to be determined, as strength loss from remolding during installation may reduce ultimate pile capacity. Shrink-swell characteristics should be investigated in expansive soils, as they affect both capacity and movement of the foundation. Since most structures requiring a pile foundation require excavation that changes the in situ soil confining pressure and possibly affects the blow count, the standard penetration test commonly performed in granular soils will probably be of limited use unless the appropriate corrections are made. It should be understood, however, that the standard penetration test is valid when applied properly. Where gravels or cobbles are expected, some large diameter soil borings should be made in order to collect representative samples upon which to determine their properties. An accurate location of the soil borings should be made in the field and a map provided in the design documents. An engineering geologist should be present during the drilling operation to provide field interpretation. The geologist must have the latitude to relocate the borings to define the subsurface profile in the best way possible. Geologic interpretations should be provided in the design documents in the form of geologic maps and/or profiles. The profiles should extend from the ground surface to well below the deepest foundation element. The accompanying text and/or maps should fully explain the stratigraphy of the subgrade as well as its engineering geology characteristics.

3-2. Laboratory and Field Testing. Laboratory determinations of the shear strength and consolidation properties of the clay and clayey soils should be performed routinely. For details of performing the individual test, refer to the laboratory test manual, EM-1110-2-1906. For the construction case in clay soils, the unconsolidated-undrained triaxial shear (Q) test should be performed. In silts, the consolidated-undrained triaxial shear (R) test, with pore pressure recorded, should be performed and used to predict the shear strength of the formation appropriate to the construction and long-term loading cases. In sands, the standard penetration test, or if samples can be collected, the consolidated-drained triaxial shear test or direct shear test (S) should be used to predict the shear strength appropriate to the two loading cases. The sensitivity of these soils should be estimated and the appropriate remolded triaxial shear test performed, as well as the shrink-swell tests, if appropriate. Consolidation tests should be performed throughout the profile so that the downdrag and/or settlement of the structure may be estimated. The field testing should include in situ ground-water evaluation. In situ testing for soil properties may also be used to augment the soil borings but should never be used as a replacement. Some of the more common methods would be the electronic cone penetration test, vane shear, Swedish vane borer, or pressuremeter. Geophysical techniques of logging the soil boring, electric logging, should be employed wherever possible if highly stratified soils are encountered or expected or if faults need to be located.

3-3. Foundation Modification. Installation of piles will densify loose, granular materials and may loosen dense, granular materials. This should be taken into consideration by the designer. For homogeneous stratifications, the best pile foundations would tend theoretically toward longer piles at a larger spacing; however, if the piles densify the granular soils, pile driving may become impossible at great depth. Pile installation affects soils from about 5 feet to 8 pile tip diameters laterally away from the pile and vertically below the tip; therefore, the designer should exercise judgement as to the effect that driving will have upon the foundation. In silty subgrades, the foundations may dilate and lose strength which will not be regained. Piles can be used to modify foundation soils by densification, but pile driving may be a costly alternative to subgrade vibration by other means. In soft clay soils piles could be used to achieve some slight gain in shear strength; however, there are more cost effective methods to produce the same or better results, such as surcharge and drainage. It may be necessary to treat piles or soil to provide isolation from consolidation, downdrag, or swell. This treatment may be in the form of prebored larger diameter cased holes or a material applied to the pile to reduce adhesion.

3-4. Groundwater Studies. The groundwater should be evaluated in each of the soil borings during the field investigation. Piezometers and/or monitoring wells should be installed and monitored during the various weather cycles. A determination should be made of all of the groundwater environments beneath the structure, i.e. perched water tables, artesian conditions and deep aquifers. The field tests mentioned in paragraph 3-2 will be useful in evaluating the movement of groundwater. Artesian conditions or cases of excess pore water pressure should also be considered as they tend to reduce the load-carrying capacity of the soil. An effective weight analysis is the best method of computing the capacity of piles. For the design of pile foundations the highest groundwater table elevation should prove to be the worst case for analysis of pile capacity. However, significant lowering of the water table during construction may cause installation and later service problems by inducing densification or consolidation.

3-5. Dynamic Considerations. Under dynamic loading, radical movements of the foundation and/or surrounding area may be experienced for soils that are subject to liquefaction. Liquefaction is most commonly induced by seismic loading and rarely by vibrations due to pile driving during construction or from vibrations occurring during operations. For dynamic loadings from construction or operations, the attenuation of the vibrations through the foundation and potential for liquefaction should be evaluated. In seismic Zones 2, 3, and 4, the potential liquefaction should be evaluated for the foundations. If soils in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. The first few natural frequencies of the structure-foundation system should be evaluated and compared to the operating frequencies to assure that resonance (not associated with liquefaction) is not induced.

3-6. Pile Load Test.

a. General. The pile load test is intended to validate the computed capacity for a pile foundation and also to provide information for the improvement of design rational. Therefore, a test to pile failure or soil/pile failure should be conducted in lieu of testing to a specified load of termination. Data from a test should not be used to lengthen or shorten piles to an extent that their new capacities will vary more than 10 percent from the test load. Finally, if the pile tests are used to project pile capacity for tip elevations other than those tested, caution should be exercised. In a complex or layered foundation, selecting a tip elevation for the service piles different from the test piles may possibly change the pile capacity to values other than those projected by the test. As an example, shortening the service piles may place the tips above a firm bearing stratum into a soft clay layer. In addition to a loss in bearing capacity, this clay layer may consolidate over time and cause a transfer of the pile load to another stratum. Lengthening the service piles may cause similar problems and actually reduce the load capacity of the service piles if the tips are placed below a firm bearing stratum. Also, extending tips deeper into a firmer bearing may cause driving problems requiring the use of jetting, predrilling, etc. These techniques could significantly alter the load capacity of the service piles relative to the values revealed by the test pile program. A pile load testing program ideally begins with the driving of probe piles (piles driven at selected locations with a primary intention of gaining driving information) to gain knowledge regarding installation, concentrating their location in any suspect or highly variable areas of the foundation strata. Test piles are selected from among the probe piles based upon evaluation of the driving information. The probe and test piles should be driven and tested in advance of the construction contract to allow hammer selection testing and to allow final selection of the pile length. Upon completion of the testing program, the probe/test piles should be extracted and inspected. The test piles, selected from among the probe piles driven, should be those driven with the hammer selected for production pile driving if at all possible. In some cases different hammers will produce piles of different ultimate capacity. Additionally, use of the production hammer will allow a correlation between blow count and pile capacity which will be helpful during production pile driving. The pile driving analyzer should be used wherever possible in conjunction with the probe/test piles. This will allow the pile driving analyzer results to be correlated with the static tests, and greater reliance can be placed upon future results when using the analyzer for verifying the driving system efficiency, capacity, and pile integrity for production piles.

b. Safety Factor for Design. It is normal to apply safety factors to the ultimate load predicted, theoretically or from field load tests. These safety factors should be selected judiciously, depending upon a number of factors, including the consequences of failure and the amount of knowledge designers have gained relative to the subsurface conditions, loading conditions, life of the structure, etc. In general, safety factors for hydraulic structures are described in paragraph 4-2C.

c. Basis for Tests. A pile loading test is warranted if a sufficient number of production piles are to be driven and if a reduced factor of safety (increased allowable capacity) will result in a sufficient shortening of the piles so that a potential net cost savings will result. This is based upon the assumption that when a test pile is not used, a higher safety factor is required than when test piles are used. If very few piles are required, longer piles as required by the higher factor of safety (3.0) may be less expensive than performing a pile load test, reducing the factor of safety to 2.0, and using shorter piles. Pile load tests should also be performed if the structure will be subjected to very high loads, cyclic loads of an unusual nature, or where highly variable soil conditions exist. Special pile load tests should be performed to determine soil parameters used in design when the structure is subject to large dynamic loads, such as large reciprocating machinery, earthquakes, etc.

d. Test Location. The pile load test should be conducted near the base of the structure with the excavation as nearly complete as possible. If the pile load test cannot be performed with the excavation completed, it will be necessary to evaluate and compensate for the additional soil confining pressure that existed during the load test. Note that casing off soils that will later be excavated does not provide a solution to this problem. Test piles should be located so that they can be incorporated into the final work as service piles if practical.

e. Cautions. A poorly performed pile load test may be worse than having no test at all. All phases of testing and data collection should be monitored by an engineer familiar with the project and pile load test procedures and interpretation. In highly stratified soils where some pile-tip capacity is used in design computations, care should be taken to keep at least 5 feet or 8 pile tip diameters of embedment into the bearing stratum. Similarly, the tip should be seated a minimum of 5 feet or 8 pile tip diameters above the bottom of the bearing stratum. The driving records of any piles driven should be used to evaluate driveability of the production piles, considering the possibility of soil densification. In clay formations, where the piles may tend to creep under load, add in holding periods for the load test and make sure that the load on the pile is held constant during the holding period. A reduction in allowable load may be necessary due to settlement under long-term sustained load (creep). The jack and reference beam should be in the same plane with the axis of the test pile since deviations will result in erroneous pile load tests.

3-7. Selection of Shear Strength Parameters. Based upon the geologic interpretation of the stratification, similar soil types may be grouped together for purposes of analysis. From the triaxial shear test and any other indicator type testing, a plot of both undrained shear strength and soil unit weight should be plotted versus depth below ground surface. If the data appear similar in this type of display, then an average trend of undrained shear strength and soil unit weight may be selected to typify the subgrade clays and clayey soils. The same procedures would be followed for silty soils with the exception that the undrained shear strength would be determined from consolidated-undrained triaxial shear tests (R) with pore pressure measurements. This would be a construction case or short-term loading case, as the Q case is called. For the long-term case, the shear testing would be represented by the consolidated-drained triaxial shear test or direct shear test (S) in all soil types. The cases referenced above are shear strength cases of the soil based upon the soil drainage conditions under which the structural loadings will be applied. The construction case is the rapid loading without pore pressure dissipation in the clay or clayey and silty soils represented by the Q case. The long-term case allows drainage of the soils before or during loading which is in general represented by the S test. This does not imply that the construction case should not include all loads upon the completed structure. Using the shear strength data from the S test, a soil strength profile may be developed using the following equation

$$s = (\Sigma h_i \gamma_i') \tan \phi + c \qquad (3\text{-}1)$$

where

s = shear strength of the soil

h_i = height of any stratum i overlying the point at which the strength is desired

γ_i' = effective unit weight in any stratum i above the point at which the strength is desired

ϕ = angle of internal friction of the soil at the point at which the strength is desired

c = cohesion intercept of the soil at the point at which the strength is desired

The two allowable pile capacities obtained for undrained and drained soil conditions should be compared and the lower of the two cases selected for use for any tip penetration. When the design is verified by pile load test, the pile load test will take precedence in the selection of ultimate pile capacity and pile tip over the predicted theoretical value in most cases. However, the test methodology should be compatible with the predicted failure mode; that is if in the predictions the S case shear strength governs, then a Quick Test should not be selected since it will best emulate the Q case. In cases where the S case governs, then the classic slow pile test should be selected. The designer should also consider using 24-hour load holding periods at 100, 200, and 300 percent of design load especially when foundation soils are known to exhibit a tendency to creep. The load test should also include rebound and reload increments as specified in the American Society for Testing and Materials (ASTM) procedures. The uses of these shear strength parameters are explained in Chapter 4.